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Planning of Logistics for Large-Scale Production of Metal-Plastic-Hybrid Components

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Abstract

According to the current state-of-the-art, manufacturing of components made of metal-plastic-hybrid materials is done in discrete manufacturing steps using basic technologies. The goal of the German Federal Cluster of Excellence MERGE (Technologies for Multifunctional Lightweight Structures) is to combine different technologies such as plastics injection molding and metal die casting by merging them and gear them towards the requirements of large-scale-production as well as energy efficiency. Thereby, new key technologies and corresponding manufacturing systems are required.
The objectives of the factory planners of the "Technische Universität Chemnitz" within MERGE were to realize a literature survey that explores conventional characteristics of large-scale-production (LSP) and to define characteristics specifically for LSP of metal-plastic-hybrid components. A literature survey that explores existing logistic concepts and planning procedures was also done. Based on this, a logistics concept and a logistics planning procedure for production systems for multifunctional lightweight structures that are produced by means of merged processes were developed. Moreover, new opportunities for production and logistic applications through the integration of sensors into metal-plastic-hybrid components were explored.

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Key words: Logistics Planning; Factory Planning; Technology Fusion; Lightweight Structures

1. Introduction

1.1. Initial Status and Potentials of Lightweight Structures

Increasing prices for resources and energy are challenging the industry in various sectors including manufacturers of production and logistic equipment as well as the automotive industry and their suppliers. Particularly, in the automotive sector, using lightweight structures can significantly save resources and energy, and reduce CO_2 emissions [1, 2].

Hence, lightweight structures made of metal-plastic-hybrid materials can lead to a weight reduction of components and in the automotive sector it can lead to less fuel consumption and the reduction of CO_2 emission. In addition, lightweight materials can be renewable and biodegradable, which supports eco-friendliness [2].

Further, potential is related to product characteristics of lightweight constructions like design, selection and combination of materials. For example, metal-plastic-hybrid components are supposed to combine the advantages of different materials within one unit. Thus, metal can provide beneficial mechanical properties (e.g. rigidity, mechanical strength), whereas plastic can have advantages in terms of tribological and ductile properties [3, 4, 5].

Other potential can come from the integration of smart components like sensors, actuators and generators in order to extent functions of lightweight structures as well [2].

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1.2. Manufacturing of Lightweight Structures and Vision of MERGE

Nowadays, manufacturing of lightweight structures is realized by using time and material consuming basic technologies (composite construction). Thus, manufacturing of lightweight structures made of different material groups such as metal, plastic or textiles is currently realized by discrete and inflexible manufacturing and assembly steps (see figure 1, state-of-the-art) [2, 6].

New key technologies for manufacturing of multifunctional lightweight structures can offer high innovation and growing potentials. One goal of MERGE is to develop those key technologies. Hence, the production processes that are currently discrete should be merged for large-scale-production (LSP) of lightweight structures in order to reduce manufacturing steps and save energy and material. In this field, new key technologies will also require novel production processes and corresponding manufacturing systems.

For example, manufacturing steps for metal and plastic components, assembly steps for the lightweight structure itself, steps for assemble sensors or actuators with lightweight structure, and further steps (e.g. steps for quality check or packaging) are taken into account as linked or merged.

The vision of MERGE is to use the potentials of lightweight structures as mentioned in section 1.1 and in addition the potentials of the key technologies to develop a long-term strategy for bivalent resource efficiency that will save energy in the use of components as well as to save energy while producing these components [2, 6].

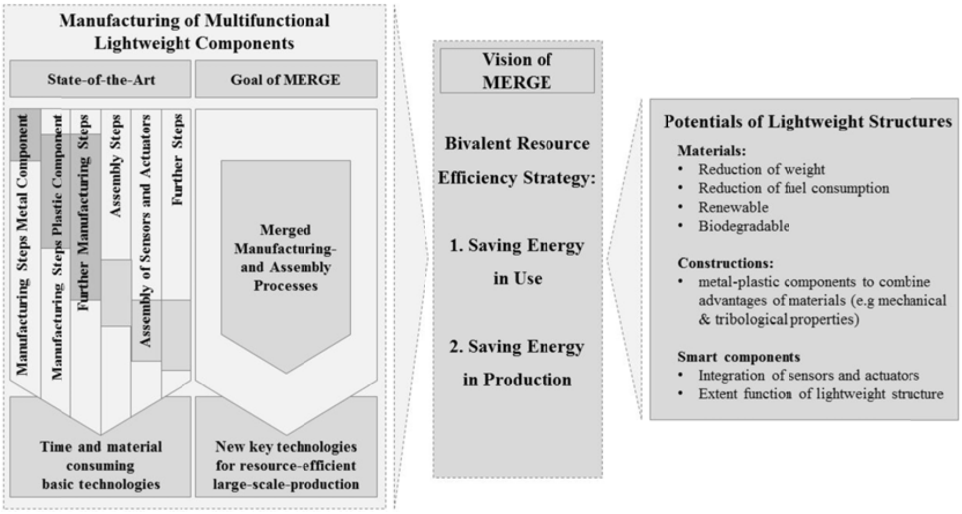


Fig. 1. Manufacturing and Potentials of Lightweight Structures, and Vision of MERGE

1.3. Project Team and Tasks of the Factory Planners

To achieve this vision a project team was created that involves more than 100 participants (engineers, researchers, technicians and administration staff) from more than 20 institutes, including “Technische Universität Chemnitz” plus researchers from “Technische Universität Dresden”, “Fraunhofer- Institut (IWU and ENAS)” and “Leibniz-Institut IFW”.

The sub-project C2 is realized by engineers from the “Institute of Conveyors and Plastics (IFK)”, “Institute of Lightweight Structure” and “Institute of Industrial Management and Factory Systems (IBF)”. The main assignment of C2 is to merge metal die casting and plastic injection molding technologies for components of lightweight conveyor systems.

The department of factory planning and factory management (part of IBF) is going to develop a logistic concept and a planning procedure for logistics of highly efficient large-scale-production (LSP) of multifunctional lightweight structures and particularly of metal-plastic-hybrid components. Those developments will be necessary due to the new key technologies and the corresponding merged manufacturing and assembly processes.

In a further step the factory planners are going to apply the logistic concept and the planning procedure in a case study. Within this case study the results will be used to plan logistics for manufacturing plastic conveyor chains with metal reinforced traction elements. In order to transfer the conveyor chains into multifunctional components it is also planned to integrate smart components. For the conveyer chain, this will be realized by sensors for monitoring the chain itself and parts that are carried by the chain.

For establishing the planned outcome, principles of concurrent engineering respectively, simultaneous engineering are used. The core of those principles is a parallel development procedure in order to shorten project time, to enhance communication and cooperation between project participants, and ultimately to reach better project results.

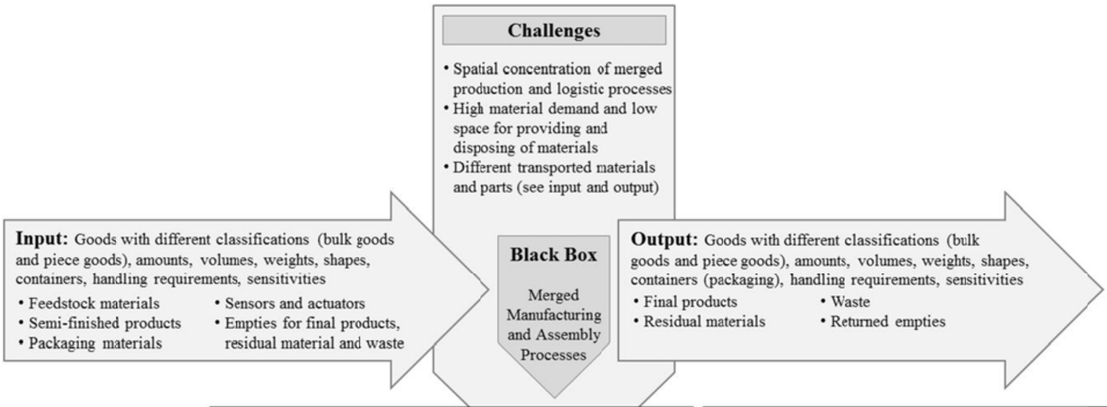
Thus, developing key technologies including merged processes and corresponding manufacturing systems that are appropriate for large-scale-production (LSP) of metal-plastic-hybrid components is already in progress. Here, first requirements for the task of the factory planners are defined. The factory planners support those development activities but it is not their main focus.

Simultaneously, the factory planners develop new solutions for logistic planning in the mentioned field of consideration. While developing the logistic concept and the planning procedure the merged processes are considered as “black box” (see figure 2), whereas now requirements for the merged processes and the corresponding production system are defined.

2. Characteristics of the Planning Task

Challenges for logistic planning result from the spatial concentration of merged manufacturing and assembly that will also lead to a spatial concentration of material and parts handling and consequently, of logistic processes. There are a lot of different inputs such as feedstock materials, semi-finished products, sensors and actuators, packaging materials, as well as empties for final products, for residual material and for waste. Outputs are final products, residual material, waste and returned empties.

Thus, for the merged processes a high material demand and handling effort is required, whereas the space for providing and disposing of materials and parts is quite limited. In addition, the material inputs and outputs consist of goods with different classifications (bulk goods and piece goods), different amounts, volumes, weights, containers (packaging), handlings, requirements and sensitivities. In figure 2 the characteristics of the planning tasks are summarized.



	Characteristics for LSP of Merged Processes	Conventional Characteristics for LSP
Production Equipment	One automated facility in spot structure or nest structure	Line structure of different workstations, machines or plants
Degree of Labor Division	low	high
Providing Materials	Adjustment and extension of basket of goods, set formation, possibly provision per order	e.g. KANBAN, MRP, JIT, CONWIP
Containers	Special container for transportation, buffering, providing, disposing of	Usually standard container for transportation and buffering
Buffering	One type of buffer before and after production steps	Different buffers before, between and after production steps
Quality Check	Completely integrated and automated	Partly separated & manually, automated or semi-automated
Facility Function Errors	Compensation of merged productions steps is difficult	Compensation with buffers or redundant capacities
…	…	…

Fig. 2. Characteristics of the Planning Task

3. Literature Survey and Results

3.1. Conventional LSP versus Merged LSP

Based on conventional characteristics for large-scale-production (LSP) [7, 8, 9, 10, 11, 12, 13], characteristics, particularly for LSP of metal-plastic-hybrid components, were defined. Figure 2 summarizes only some examples for those characteristics.

Conventionally, the arrangement of production equipment for LSP relies on process sequencing, object-orientation, arrangment within a line structure and the degree of labor division being high. In contrast, the goal for merged processes is to establish one automated facility in one spot or nest structure with a low degree of labor division.

The typical concepts for providing materials in LSP (e.g. KANBAN, MRP, JIT and CONWIP) can be used for the goals of MERGE. However, they do not completely support the requirements due to the special concentration of the logistic processes. Thus, a new concept based on these concepts and further existing concepts that are primarily applied during the assembly of multi-variant small and medium batch production (e.g. basket of goods, set formation and possibly provision per order) should be adjusted and extended.

Usually LSP standard containers for transportation and buffering are used. For the merged processes the plan is to design special containers with extended functionality. In addition to transportation and buffering, the container will be designed for providing and disposing of materials and parts directly using special interfaces between containers and the automated facility. The special containers will also merge different buffers, so that there will be only one type of buffer before and after the production steps.

Nowadays, quality checks during conventional LSP can be manual, automated or semi-automated, whereas there are partly separated facilities (e.g. manual workstations or automated cells) for quality checks only. The goal of MERGE is to completely integrate and automate those processes.

Within conventional LSP function errors of facilities can be compensated with e.g. buffers or redundant capacities. Merged production processes in one automated facility can make such compensation difficult. So, there is a risk that a function error of only one production step can lead to a stop of the entire production process.

3.2. Logistic Concepts

Based on the characteristics of the planning task, the state-of-the-art of logistic concepts was investigated, whereas the understanding of "logistic concept" is different: the technical term is not clearly used or there are other terms for this expression. Their application and their level of detail are different. For example, there are general concepts with a description of general characteristic or attributes for logistics. There are more concrete concepts that are either related to a special part or to the entire logistic system including information about material flow, material providing and logistics control.

Therefore, the application of the new logistics concept was determined based on the literature [14]. The considered planning levels consist of the tactic and strategic level and the function area is production and here, particularly production logistics. The concept will be described by general attributes, material providing and logistics control, material flow and logistic processes.

Within the literature survey more than 70 logistics concepts and characteristics of logistics systems were investigated and reviewed regarding their applicability for the new planning task. Based on this investigation, existing concepts as main bases for the development of the new logistic concept were determined. These are material providing per order, material providing in sets, product specific parts basket and summarized material providing per order [13, 15, 16, 17]. Some of the general attributes of these concepts and their adaption for the new logistic concept are described in section 4.1.

3.3. Planning Procedures

Another emphasis of Project MERGE is the development of a procedure for the logistic planning of production systems for multifunctional lightweight structures that are produced using merged processes.

For this, the state-of-the-art of planning procedures was explored and evaluated. Here, more than 10 planning procedures in the fields of production, logistics and material supply were investigated.

As a result the procedures by Pawellek, Hompel, Bullinger und Kettner were identified as the bases for the new planning procedure [19, 20, 21, 22]. Here, planning phases and steps were deduced and extended, and further steps, particularly to implement the new logistic concept, were established.

4. Development of a Logistic Concept

4.1. General attributes

The field of application of existing concepts (material providing per order, material providing in sets, product specific parts basket and summarized material providing) that were used as the bases for developing the new logistic concept is usually multi-variant product assembly in small and medium batch production. These will be adapted during the new logistics concept so that they are suitable for low-variant manufacturing and assembly in large-scale-production.

Table 1. Main Bases and Attributes

Main bases: material providing per order, material providing in sets, product specific parts basket and summarized material providing per order	
Attributes of the Existing Concepts	**Adaption for the Logistic Concept**
Field of application	
Usually multi-variant product assembly in small and medium batch production	Low-variant manufacturing and assembly in large-scale-production
Basis for Dimensioning of Container Capacity	
Order, set, product	Optimal ratio between numbers of transportation cycles and required space
Basis for Pre-packing of Containers and Providing Materials	
Material types and amounts depend on order, set or product	Material types and amounts are constant

Within the existing concepts the basis for dimensioning of container capacities are based on orders, sets or products. In contrast, the basis for the new concept is the optimal ratio between the numbers of transportation cycles and required space.

Material types and amounts depending on orders, sets or products are bases for pre-packing of containers and providing material of the existing concepts. The material types and amounts within the new concept are constant.

4.2. Material Providing and Logistics Control

The existing concepts, as mentioned in section 3.2 (material providing per order, material providing in sets, product specific parts basket and summarized material providing per order), provide further knowledge that can be used and adjusted particularly for material providing of the new concept. There are useful contents that results from only one existing concept or contents that is part of more than one concept.

Those contents are e.g. the compilation of sets including all input materials for a pre-determined product amount, whereas within the new concept the basis for dimensioning is the optimal ratio between numbers of transportation cycles and required space (see table 1). Moreover, for the new concept special developed containers will be designed and established. These containers will be applied directly within the production facility (for functions of the containers see section 3.1)

Another existing point is the pre-packing of containers including all required materials and parts in a separate picking area. Here, the challenge is the input variety with e.g. different classifications (bulk goods and piece goods), shapes, handling requirements and sensitivities (e.g. bulk goods versus sensors and actuators).

The procedure of direct delivery of containers to the production will be also adjusted. Thus, the containers that are going to be particularly established for the merged processes will be directly delivered and integrated into the automated facility.

The material supply will be supported by existing solutions for logistics control. For this purpose, a suitable concept is eKANBAN for triggering the material income by the KANBAN principle that is extended using the radio-frequency identification (RFID) technology and a special software cockpit for monitoring of the container positions and their content [18]. Furthermore delivery of materials to the production will be realized based on Just-in-time, and the principles of Poka Yoke, especially the error prevention strategies to place containers considering interfaces will be applied within the new concept.

4.3. Material Flow and Logistic Processes

The material flow and initial approaches for the logistic processes are shown in figure 3. The left side shows the main cycle.

In the picking area, all input materials and parts are transferred into the special containers. At the same time final products as well as waste from the previous cycle are transferred from the container to the picking area. Now, the parts of the container with material are filled up and the parts for products and waste are being emptied.

The next step is the transportation of the container to the production respectively the automated facility. After this, the container gets inwardly transferred directly into the production facility. Now, material and parts will be provided for the merged production processes, and waste and the final products are transferred to the container.

In a next step the container is removed out of the production facility and transported back to the picking area where the final products and waste is discharged and a new cycle starts.

As mention in section 1.3, the development of the required key technologies including merged processes and corresponding manufacturing systems is currently in progress. The right side of figure 3 illustrates two variants for approaches for realizing the key technologies within the production facility.

Variant 1 is a production facility without transferring the container respectively with only one station within the facility. In contrast to this, the facility in variant 2 has more than one station and the containers are transferred inside of the facility from station to station. Currently, it is not fixed which variant will be realized. If it will be variant 2 it is also not clear, how many stations will be required for the merged processes.

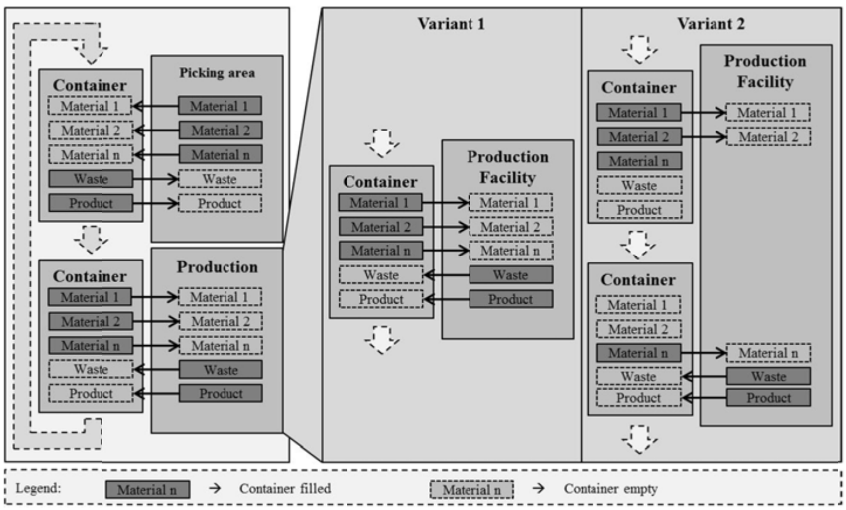


Fig. 3. Scheme for Material Flow and Logistic Processes

5. Development of a Planning Procedure for Logistic

Based on existing procedures [19, 20, 21, 22] as outlined in section 3.3, a new procedure for logistic planning of production systems for multifunctional lightweight structures that are produced using merged processes was established.

Phase 1 comprises the definition of the planning project where objectives, tasks and system limits have to be determined. The preparation of project organization and project management is also part of this phase.

In phase 2 the required input information such as production program, products (structure, materials, parts, sensitivity etc.), functions, processes, framework conditions, classification and description of goods will be compiled and analyzed.

The establishment of variants for logistic processes based on the new logistic concept (see section 3.3) is part of phase

3. The concept of material flow and logistic processes has to be adjusted and detailed for the specific production system and the evaluation as well as the selection of a preferred variant will be done.

Phase 4 is detailed planning and consists of dimensioning, design and technical realization of containers, integration of the preferred variant in the production environment including interfaces to existing processes and technical design of interfaces.

Within phase 5, the factory layout focusing the new logistic processes will be elaborated, and transport routes, providing areas and technical specification of interfaces are worked out. Now, the logistic system is supposed to be ready for implementation and optimization during the start-up phase.

The development of the planning procedure has to be systemized and illustrated by means of input information, planning tasks, planning methods and tools, and output information. In order to make the planning procedure more understandable, it is applied within an exemplary case study for the production of conveyor chains with metal reinforced traction elements and integrated sensors for monitoring tasks.

6. Summary and Outlook

The use and production of lightweight structures such as metal-plastic-hybrid components offer high potential in saving resources and energy. In order to realize this potential, the main goal of the German Federal Cluster of Excellence MERGE (Technologies for Multifunctional Lightweight Structures) is to develop key technologies for merged processes in large-scale-production (LSP) of lightweight components.

In comparison to conventional LSP, the characteristics of merged production and logistic processes, and corresponding facilities are partly different. Particularly for the new requirements in logistics, the factory planners of Technische Universität Chemnitz develop an appropriate logistic concept and a logistic planning procedure.

Following steps are the implementation of the logistic concept and the development of a demonstrator for merged production of metal-plastic-hybrid components using the example of a reinforced conveyor chain.

The demonstrator will enable the investigation and improvement of the new developed logistic solutions. Moreover, it is planned to adapt these solutions for further technology combinations and to generalize them in order to produce other hybrid components.

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